Bending Capacity of Styrofoam Filled Concrete (SFC) Using Truss System Reinforcement

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***Abstract*— Reinforced concrete has been used widely to accelerate infrastructure development. Concrete material is formed by mixing cement, aggregate, and water. Aggregates generally use gravel and crushed stone, which is obtained from the exploitation of natural materials and will have an impact on the environmental damage. Therefore, creative effort is needed, so that concrete material can be used as efficiently as possible. Based on the hardened concrete properties and from the viewpoint of engineering mechanics, concrete structures in a flexural system will occur tensile and compressive action to produce a resistant moment, thus concrete on the tension zone does not contribute directly in resistant moment. Volume of concrete in the tension zone can be reduced by utilizing Styrofoam waste as filler to produce a concrete material containing granules Styrofoam, hereinafter called Styrofoam filled concrete (SFC). Reinforced concrete beams using SFC-50 (Styrofoam 50% by volume), bending capacity in the tension zone decreased by 40%. Consequently, SFC affects the compression strut on the beam bending action. Therefore, it needs compression strut action to replace compression strut weakening in SFC by using truss system reinforcement. Truss system reinforcement is used to take advantage of truss action in improving the bending capacity of beams using SFC. The objective of this study is to determine the bending capacity of beams using SFC on the tensile zone and truss system reinforcement.**

Keywords*— Reinforced concerete beam; truss system reinforcement; Styrofoam.

I. INTRODUCTION

Concrete is the most widely used material in the world and it is estimated that the annual global production more than 2 billion cubic meters [1]. Concrete is made from a hardened mixture of cement, water, fine aggregate and coarse aggregate. As the main constituent of concrete materials, deposits of natural materials decreases, so that necessary to improve to the study on the efficiency of the assessment of natural materials that are used in the optimum design of building structures, especially in the bridge girder.

From various theory relating to the analysis of structural element concrete beams, as note that the part that works optimally in support and withstand bending force only the bottom of cross section, which is in the compression area of concrete, while strength in the tension area of concrete is negligible [2]. Therefore it is not efficient when the concrete core parts that are not working optimally made from the same type of concrete with which working optimally.

Seeing these inefficiencies, and then it occurred to make concrete which consists of several different layers [3]. One way to do is by the design efficiency of structural elements made of concrete beams using normal concrete in a particular layer, while the other part is filled with lightweight concrete styrocon by using styrofoam.

Polystyrene is produced from styrene ($C_6H_5CH_9CH_2$) which can not be decomposed by soil, thus reducing the quality of the fertility of the land, when burned produces carbon oxides (CO_X) which lead to global warming, as well as the combustion of a liquid plastic that can lead to pollution of soil and water. Therefore, it is necessary to keep environmental friendly by using concrete technology which reuse the waste on the beam structural element to reduce the pollution. In addition, the use of lightweight concrete styrocon in the core layer or bottom layer of normal-lightweight beam to reduce the construction weight, also has been used for environmental aspects.

The use of styrofoam as concrete material by utilizing waste for concrete can reduce construction costs, slow the onset of the heat of hydration, reduce the weight of concrete volume, and reduce the work load of earthquakes because weight of concrete structures is reduced [4,5]. In the end, the exploitation of natural materials such as sand, gravel, and cement for building materials can be reduced.

Motivation to investigate the performance of sandwich beams of normal and lightweight concrete is to design structural elements that utilize the most advantageous properties of two different concrete quality in one section.

Sandwich beams are used in applications requiring high bending stiffness and strength which combined with low weight [6,7].

Studies of truss system reinforcement for structural elements have been conducted by several researchers such as Salmon et. al. [8] which used steel trusses on the panel to reduce shell deflection. Deshpande et.al. [9] conducted experimental sandwich beam, which consists of a triangular truss core face-sheets, which have been casted with aluminum-silicon alloy and silicon in brass to get macroscopic stiffness effectively and strength sheet face-sheets, as well as tetrahedral core. Kocher et. al. [10] presented a theoretical approach to study several issues related to the design of sandwich structures with a polymer frame reinforced hollow core using a simple analytical model that describes the contribution to the stability of the structure is hollow at the core. Liu et.al. [11] studied a multi-parameter optimization procedure on the panel Ultra-lightweight truss-core sandwich. Optimization to improve structural performance of each panel in the case of multiple loading and minimize structural weight simultaneously. Kabir [12] developed a method to investigate the mechanical characteristics of the 3D sandwich wall panel in shear and flexural static loading in order to understand the structural components.

Generally, the research related to the utilization of waste syrofoam for elements structure like beam, with the goal of efficiency use of natural materials in concrete construction and application for environmentally sustainable technologies is still rarely performed. In this regard, it is important to expand the use of styrofoam as substitution material or partial replacement of natural materials. A series experimental research has been done. This paper presents the results of a study related to the flexural capacity of concrete beams using material with styrofoam-filled.

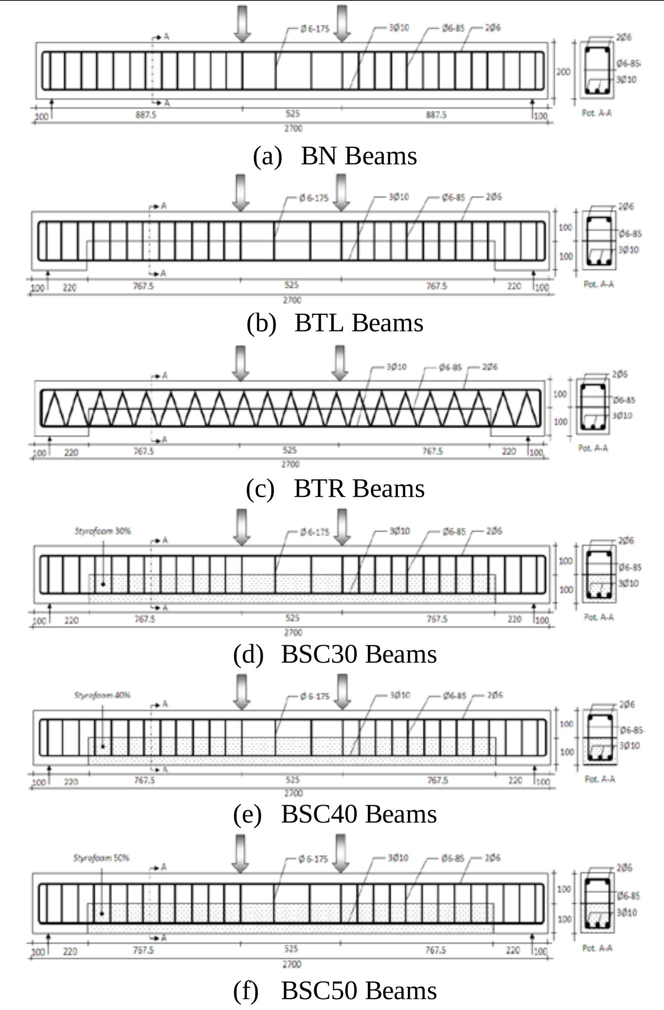
II. SPECIMEN AND TEST SET UP

Fig. 1. shows specimen model geometry for control beam (BN), external transverse reinforced beams (BTL), external truss system reinforced beam (BTR), normal-styrocon beam with styrofoam content of 30% (BSC30), normal-styrocon beam with styrofoam content of 40% (BSC40), and normal-styrocon beam with styrofoam content of 50% (BSC50), respectively. Specimens BN as a control beam, while BTL, BTR, BSC30, BSC40 and BSC50 as a competitor, which provide description the strength and efficiency of natural materials usage.

TABLE I. CHARACTERISTICS OF CONCRETE AND REINFORCEMENT

Concrete			Steel	
Parametric	***Normal***	***Styrocon***	***Parametric***	***Value***
Compressive strength	26,0 MPa	12,2 MPa	f_y	458,27 MPa
Tensile strength	3,0 MPa	1,38 MPa	f_{smax}	442,32 MPa
Flexural strength	3,81 MPa	3,32 MPa	ε_s	0,00253
Modulus of elasticity	23.219 MPa	14.337 MPa	E_s	209.787 MPa

a. *Based on the result of experimental



(a) BN Beams

(b) BTL Beams

(c) BTR Beams

(d) BSC30 Beams

(e) BSC40 Beams

(f) BSC50 Beams

Fig. 1. Details of test materials

As shown in Fig. 1, all specimen have cross section of 150 mm x 200 mm, with specimen length of 2700 mm. In the tension area of specimen, three plain bar diameter 10 mm were embedded. To facilitate the assembly of reinforcement, then on the compression area are also embedded two plain bars with diameter of 6 mm. In order to fix the position of longitudinal bars, shear reinforcement with diameter of 6 mm were placed. Then concrete with compressive strength target of 25 MPa was poured. Casting process is done according to SNI standard, then curing in temperature room for 28 days. The compression and splitting test were performend on cylinder specimens, and a simple beam for tensile strength test which were conducted to determine the mechanical properties of concrete. In addition, tensile test for reinforcing bar was also performed. Mechanical properties of concrete and reinforcing bar are presented in Table I.

Weight per volume of styrofoam is 13.8 gr/cm^3 and characteristic of styrofoam as based material are described in Table II.

TABLE II. SPECIFICATIONS OF EXPANDED POLYSTYRENE/STYROFOAM

Specifications	
Grain size of styrofoam	3 mm – 5 mm
Density of styrofoam	13 – 22 kg/m^3
Modulus Young's (E)	300 – 3600 MPa
Tensile strength of styrofoam	40 – 60 MPa
Spesific heat of styrofoam (c)	1,3 kJ/(kg.K)
Thermal conductivity styrofoam (K)	0,08 W/(m.K)

Fig. 2. Test set up

Testing was performed by loading method as shown in Fig. 2, reinforced concrete beams normal (BN). Specimens were tested as a simple beam with long span of 2500 mm. Load is given in the form of 2 point load, 500 mm as centric at midspan. Loading is given in stages per 1 kN using a hydraulic jack. Deflection was measured by placing 3 pieces of LVDT (Linear Variable Displacement Transducer) on the center span and under point load. Jack dial load readings was recorded at each increase of 1 kN. In addition, cracks that occur are also observed, then made a sketch. The propagation of cracks was observed, then selected 3 major cracks to be analyzed.

III. ESTIMATED FLEXURAL CAPACITY

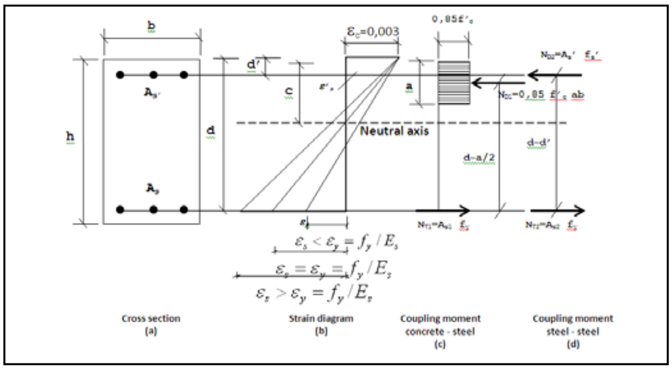


Fig. 3.Model of stress-strain

Fig. 3 illustrates the basic assumption of stress, strain, and forces of cross section for analysis of flexural capacities. The assumption are based on under reinforced condition ($\rho s < \rho sb$). Based on the flexural theory of reinforced concrete [13], and used in this analysis that strain varies linearly in the cross section, and as consequence of perfect adhesiveness between the concrete and reinforcing bars, hence collapse condition of concrete strain is achieved at 0.003. It is also assumed that the concrete compressive stress on the capacity of the main cross-section is rectangular and reinforcing bar behave elasto-plastic.

Based on the assumptions described above, then was done testing of forces, stress and strain in cross-section beam that work to restrain the moment ultimate (Mu), which is caused by the external load and lead to failure. Flexural strength of concrete beams occurs due to ongoing mechanisms in stress-strain at cross section of beam, in certain circumstances can be represented by the internal forces. Where ND is internal resultant compressive force and located above the neutral line. While the NT is internal resultant tensile force and planned for the area just below the neutral line. Resultant compressive force and tensile force are parallel to the line of work but the opposite direction. These resultant force is equal to the z distance to form coupling in internal moment, where the maximum value is referred to flexural strength.

The internal moment will carry bending moments which caused by the actual plan of external load. For planning purposes, the condition of the beam must be prepared in accordance with load composition, concrete beam dimensions and amount of reinforcement area to resist the moment due to external loads. Firstly, to determine the total resultant concrete compression force N_D, and line of action location is calculated by pressing toward the outer edge of the cross section, so that the z distance can be calculated. N_D and N_T values can be calculated by simplifying the linear curve of stress distribution by an equivalent rectangle, by using the stress intensity value of a mean order value and the resultant layout is not changed.

Initial cracking moment is calculated by:

$$M_{cr} = f_r \,.\, I_{gt} \;/\; y_b \tag{1}$$

The American practice, as represented by the ACI committee 318 has been replaced the actual stress block by the equivalent rectangle. The rectangle has a mean stress of 0.85f'c and a depth a, where:

$$a = \beta_1 \,.\, c \tag{2}$$

For under reinforced beam, bending failure is marked by the yielding of reinforced bar, occurs when concrete compressive stress is smaller than fc' ($f_c < f_c$ ') in elastic limit where the value $f_s = f_y$. So the moment that happened refer to (3):

$$M_y = f_y \,.\, A_s \,.\, j_d \tag{3}$$

After the stress in the steel equal to the yield strength occurred then it is said that reinforced beam has undergone ductile bending. In the case of flexural beam, ductile deformation occurred despite the tensile reinforcement has not yielded.

From the force balance equation $C_c + C_s = T$, then refer to (4):

$$A_s \,.\, f_y = 0.85 f_c \,.b \,.\, a + A_s' \,.\, f_y \tag{4}$$

or refer to (5):

$$a = (A_s \,.\, f_y - A_s' \,.\, f_y)/(0.85 f_c \,.b) \tag{5}$$

while to determine the ultimate moment refer to (6):

$$M_u = 0.85 f_c \,.a.b(d\text{-}a/2) + A_s' \,.\, f_y\,(d\text{-}d') \tag{6}$$

Table III shows the estimation results for the ultimate moment of each test material using the material properties which are presented in Table I. Moment of initial crack is estimated by using the elastic flexural theory [13]. For the ultimate moment, estimating was carried out under conditions where failure occurs after a compression reinforcement in the concrete yielded by using eq. (5).

TABLE III. VARIOUS VALUE OF BEAM

Beam code	**Initial crack**		**Ultimate load**		**Ratio**
	M_{cr} (kN.m)	P_{cr} (kN)	M_u (kN.m)	P_u (kN)	*(x/BN)*
BN	4.28	7.54	14.77	28.77	1.00
BTL	1.21	2.00	12.51	28.77	1.00
BTR	2.82	4.50	14.84	28.90	1.00
BSC30	2.05	3.02	15.09	29.42	1.00
BSC40	1.56	2.01	15.09	29.42	1.02
BSC50	1.22	1.34	15.09	29.42	1.02

IV. RESULT AND DISCUSSION

A. *Load and Deflection Relationship*

Fig. 4 shows the relationship between load and deflection of each specimen. In BN beam, early loading is a straight line that shows the elastic behavior until the mean load of 8 kN (working stage). In line with the increased load, the relationship of load and deflection is more gentle than before. This occur until mean load of 32 kN (yielding stage). At the time of yielding steel, a lot of experience characterized by large deflections without a corresponding increase in the average load, and the load deflection curve is much flatter than before. This occurs until the ultimate mean load of 37 kN (failure stage).

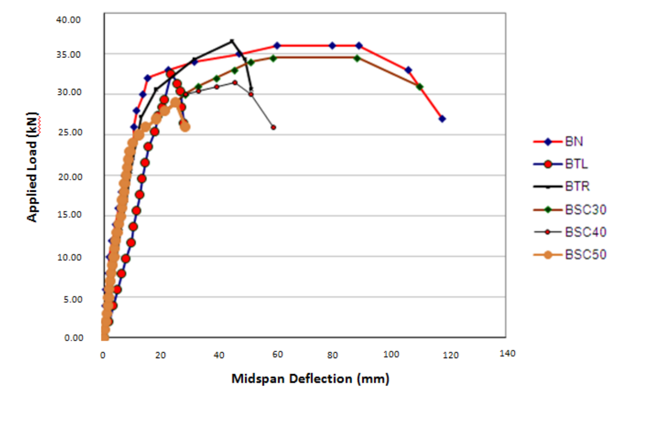


Fig. 4. Relationship between load and deflection

In BTL beam, a curve shows a lower ultimate response than BN and relatively brittle. While on BTR with truss system reinforcement exhibits an increase in ultimate load compared to BTL, but low ductility. BSC30 beam shows a condition more ductile than BN beam with addition of styrofoam by 30% in the tensile area of concrete. So it can conserve the use of natural materials and utilize of waste on the element structure beam. Both BSC40 and BSC50 beam show a lower capacity than BSC30.

B. *Flexural Capacity*

TABLE IV. INITIAL CRACK AND ULTIMATE LOAD TEST RESULT

Code Beam	Theory		Experimental		Ratio	Exp/Theo
	P_{cr} (kN)	P_u (kN)	P_{cr} (kN)	P_u (kN)	(x/BN) exp.	
BN(1)	7.54	28.77	8.00	37.50	1.00	1.303
BN(2)			8.00	36.00	1.00	1.251
BN(3)			8.00	36.50	1.00	1.269
BTL(1)	2.00	28.77	2.00	32.30	0.881	1.123
BTL(2)			2.00	31.50	0.859	1.095
BTL(3)			2.00	28.00	0.764	0.973
BTR(1)	4.50	28.90	4.00	36.60	0.998	1.266
BTR(2)			4.00	35.10	0.957	1.215
BTR(3)			4.00	35.60	0.971	1.232
BSC30(1)	3.02	29.42	4.00	34.00	0.927	1.156
BSC30(2)			4.00	33.00	0.900	1.122
BSC30(3)			4.00	34.50	0.941	1.173
BSC40(1)	2.01	29.42	3.00	30.50	0.832	1.037
BSC40(2)			3.00	31.00	0.845	1.054
BSC40(3)			3.00	31.50	0.859	1.071
BSC50(1)	1.34	29.42	2.00	29.00	0.791	0.986
BSC50(2)			2.00	29.00	0.791	0.986
BSC50(3)			2.00	29.00	0.791	0.986

The ultimate load of BSC50 beam was achieved at the level of 29.0 kN load. When it compared with the theoretical estimation by using stress and strain assumptions that is described above, shows good results with a similar ratio about 98.6%. This result indicates that specimen of BSC50 behave as assumed in the theoretical estimation.

For BTL specimen has the lowest flexural capacity compare BTR and BN specimens, and behave brittle. BTR beams have flexural capacity closest to BN, but showed no ductile characteristics. The same value is also shown by BSC30 beam with flexural capacity approaching BN, and exhibit the behavior more ductile than others, which gives the efficient use of natural materials, such as sand, gravel, and cement by 30% replacement in the tension area.

BSC40 and BSC50 specimens present a lower ultimate load. Thus provide less bending capacity than BN specimen.

C. Cracks and Failure Pattern

Generally, the pattern of cracks that occur are flexural cracks as shown in Fig. 5. These crack began when the force stress occurs exceeded the tensile strength of concrete material. Increasing the load will cause the spread of adhesiveness pointing up toward the neutral line of beam and the emergence of new cracks.

Failure beam at maximum load is characterized by cracks width and steel yield is characterized by a large deflection of beam, which has destroyed the compression area. On reinforced concrete beams with Styrofoam-filled, the length of cracks which occur shorter than in reinforced concrete beams normal (BN).

Monitoring of three cracks propagation in each specimen is presented in Fig. 6. As you can observe on BN beams that cracks began to spread when the load is at level about 8 kN. Cracks continue to spread until they reached ultimate load. On BTL and BTR beams with externally reinforced, it can be observed that cracks began to spread after load is at a level slightly higher than the initial crack load BN beam, but failure faster because the initial cracks have formed in the compression area of the concrete beams.

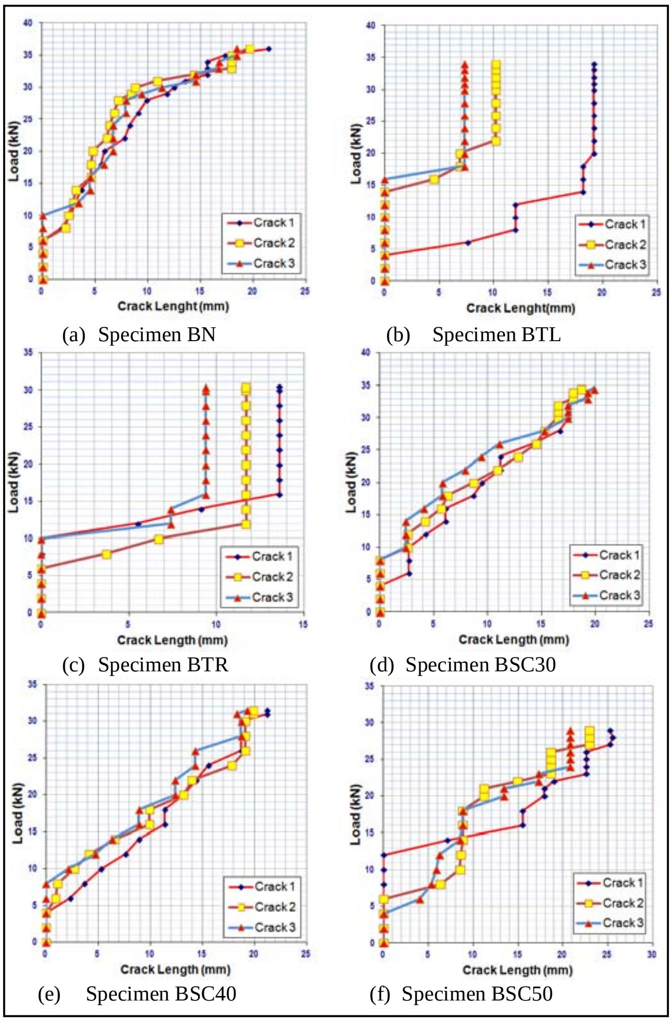


Fig. 5. Crack propagation pattern

Based on the pattern of cracks and crack propagation phenomena as shown in Fig. 5 and Fig. 6, it can be concluded that the beam with Styrofoam-filled give advantages and well conditions, the length of crack propagation patterns are not straight up, compared to the normal beam (BN) and externally reinforced beams (BTL and BTR), due to the addition of expanded polistyerene styrocon whose have more elongation than normal concrete.

Fig. 6 shows the crack propagation of all specimens. Furthermore, all specimens exhibit flexural failure. However, BTR specimen with truss reinforcement shows reduction in deflection, but after the compression area of concrete cracked directly experiencing failure. In the normal beam (BN) damage also occurred to the upper part of the concrete. While failure in the normal- styrocon composite concrete, cracks occur until the high rectangle block of Whitney, causing the tensile strength styrofoam-filled concrete is better than normal concrete.

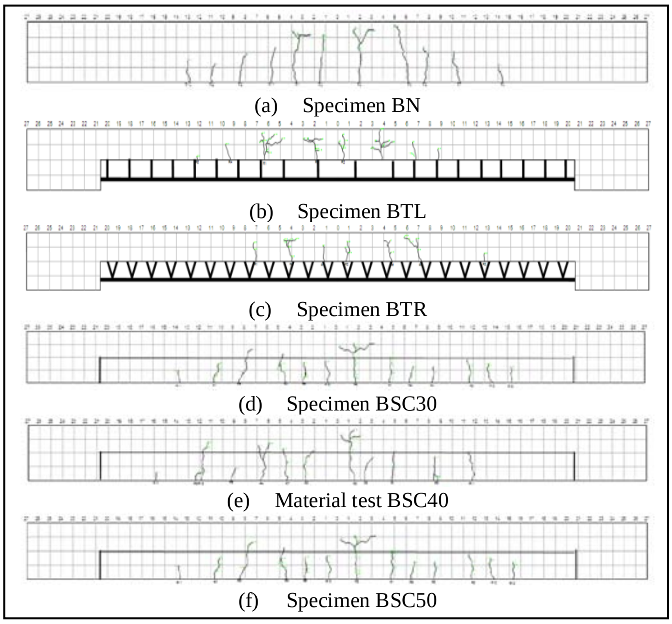


Fig.. 6. Direction of crack propagation

V. CONCLUSION

Based on the testing and analysis, it can be drawn some conclusions as follows:

1. Relationship between load and deflection in the normal-styrocon composite concrete beams with addition 30% of styrofoam exhibits the behavior quite well on ductility displacement than normal concrete beams. Moreover, it can efficiency the use of natural materials, such as sand, gravel, and cement by 30% on the tension area of cross-section and reduce the weight of construction and reuse of waste or garbage white wrapping cork electronic devices.
2. Flexural capacity of composite concrete beams with normal-styrocon (addition of 30% styrofoam), have the ability to restrain ultimate load of 34.5 kN, and the addition of expanded polistyerene styrocon on tension

area has resulted in higher elongation than normal concrete, so it has better flexibility as well.

3. In the normal-styrocon composite concrete beams with the addition 30% of styrofoam, crack length is happening shorter than in normal reinforced concrete beams and external reinforced concrete beam where crack propagation patterns are not straight up.
4. Experimental results show 98.6% similarity ratio of the theoretical estimates, this indicates that the test substance behaves as assumed in the theoretical estimation.

It is important to develop methods of strengthening the ability of adhesiveness between the two layers of normal-styrocon composite concrete to increase the strength and stability of the sandwich concrete beams.

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